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<b>(21) International Application Number:</b> PCT/US00/11691 <b>(22) International Filing Date:</b> 26 April 2000 (26.04.00)  <b>(30) Priority Data:</b> 60/133,164      26 April 1999 (26.04.99)      US  <b>(71) Applicant:</b> CALIFORNIA INSTITUTE OF TECHNOLOGY [US/US]; 1200 East California Boulevard, Pasadena, CA 91106 (US).  <b>(72) Inventors:</b> HUBBELL, Jeffrey, A.; Unterdorfstrasse 18, CH-8126 Zumikon (CH). KORNFIELD, Julia, A.; 1675 Oakdale Street, Pasadena, CA 91106 (US). TAE, Giyoong; 1001 East Villa Street, #28, Pasadena, CA 91106 (US).  <b>(74) Agent:</b> BIEKER-BRADY, Kristina; Clark & Elbing LLP, 176 Federal Street, Boston, MA 02110-2214 (US).	<b>(81) Designated States:</b> AU, CA, JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i>	
<b>(54) Title:</b> <i>IN SITU</i> FORMING HYDROGELS  <b>(57) Abstract</b>  The invention features materials and methods for the liquid to solid transition of an injectable pre-hydrogel composition to a hydrogel. These methods can be carried out <i>in situ</i> .		

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## IN SITU FORMING HYDROGELS

### Background of the Invention

5           The present invention relates to materials and methods for inducing *in situ* transitions of a hydrogel precursor compositions from an injectable state to a hydrogel.

          A mechanism for gently transitioning a hydrogel precursor composition from a liquid state to a solid state such that the transition can be  
10   carried out *in situ*, directly in intimate contact with sensitive biological materials, is of special interest for medical purposes. After being delivered in a liquid state, the *in situ* formation of a hydrogel at an implantation site has two potential advantages: the ability to match the morphology of a material implant to various complex tissue shapes in the body, and the ability to deliver a large  
15   device through a small hole in the body via minimally invasive surgery (Hubbell, MRS Bulletin, November issue, 33-35, 1996). In addition, this type of transitioning system can be used as a carrier for the controlled release of drugs, for the delivery of living cells in cell transplantation, as a barrier for the prevention of postoperative adhesions, or as a structural support at tissue sites.

### Summary of the Invention

20           We have developed methods and materials for the transition of a hydrogel precursor composition to a hydrogel. These methods and materials are sufficiently gentle that the transition can be carried out *in situ*, for example in direct contact with a tissue. The methods of the invention can be performed  
25   without the use of any complex instrumentation or high temperatures that might otherwise be harmful to the tissue at the site where the gel forms. The

hydrogels that result from these methods possess high mechanical strength, and degradation rates that are of therapeutic use. In addition, these hydrogel precursors can be constructed to form in a manner that is selective for the intended target site, i.e., the transition to the precursor composition a hydrogel state can be controlled so that undesired chemical reactions with surrounding tissues do not occur.

In a first aspect, the invention features a hydrogel precursor composition comprising a polymer, wherein the polymer comprises a water soluble polymer domain with at least two hydrophobic interacting groups attached to it, and wherein the polymer is capable of assembling into a hydrogel under physiological conditions. The hydrogel precursor composition also comprises a physical chemical protecting group that prevents gelation of the hydrogel precursor composition until desirable.

In a second aspect, the invention features a hydrogel or hydrogel precursor composition comprising a polymer, wherein the polymer comprises a water soluble polymer domain with at least two hydrophobic interacting groups attached to it, and wherein the polymer is capable of assembling into a hydrogel under physiological conditions. The hydrogel or hydrogel precursor composition also comprises a physical chemical protecting group that prevents gelation of the hydrogel precursor composition or hydrogel. The hydrogel or hydrogel precursor composition further comprises a molecule that disrupts an interaction between the physical chemical protecting group and the hydrophobic interacting groups.

In one embodiment of the above two aspects of the invention, the polymer domain comprises poly(ethylene glycol) (PEG), poly(vinyl alcohol), poly(vinyl pyrrolidone), poly(ethyl oxazoline), poly(acrylic acid), poly(acrylamide), poly(styrene sulfonate), poly(amino acids), polysaccharides, or copolymers thereof. Preferably the polymer domain comprises

poly(ethylene glycol). In another embodiment, the hydrophobic interacting groups are hydrocarbons, preferably perfluorinated hydrocarbons. In yet another embodiment, the physical chemical protecting group is cyclodextrin, preferably  $\beta$ -cyclodextrin.

- 5           In other embodiments, the physical chemical protecting group is a molecule that covalently binds to the hydrophobic interacting group. Preferably the molecule is hydrophilic. The polymer of the first or second aspects may be linear or branched, and may comprise a multi-arm poly(ethylene glycol). The hydrophobic interacting groups may be positioned
- 10   at the termini of the polymer domain, or within the polymer domain. The linkage between the polymer domain and the hydrophobic interacting groups may be stable or degradable. Preferably the degradable linkage is an anhydride linkage, an ester linkage, a carbonate linkage, an amide linkage, or an oligomeric linkage. In a preferred embodiment, the oligomeric linkage
- 15   comprises oligomers of lactic acid, glycolic acid, or epsilon-caproic acid, or oligomers of trimethylene carbonate, or co-oligomers thereof.

          In other embodiments, the hydrophobic interacting groups interact with the physical chemical protecting group through a noncovalent bond. Preferably the interaction occurs by the formation of an inclusion complex.

- 20           In still other embodiments, the molecule that disrupts an interaction between the physical chemical protecting group and the hydrophobic interacting groups is a molecule that binds to the physical chemical protecting group better than the hydrophobic interacting groups bind to the physical chemical protecting group. Preferably the molecule that disrupts an interaction
- 25   between the physical chemical protecting group and the hydrophobic interacting groups is a one-end modified polymer domain. Most preferably the one-end modified polymer domain comprises poly(ethylene glycol), and is modified with a perfluorinated hydrocarbon.

In still other embodiments, the molecule that disrupts an interaction between the physical chemical protecting group and the hydrophobic interacting groups is a molecule that degrades the linkage between the physical chemical protecting group and the hydrophobic interacting groups, or is a molecule that degrades the physical chemical protecting groups themselves. Most preferably a molecule that degrades the physical chemical protecting group is  $\alpha$ -amylase or amyloglucosidase.

In one embodiment of the second aspect of the invention, the polymer domain comprises poly(ethylene glycol), the hydrophobic interacting groups are perfluorinated hydrocarbons, and the chemical protecting group is  $\beta$ -cyclodextrin.

In a third aspect, the invention features a method for forming a hydrogel in contact with a tissue, involving providing a solution comprising a polymer, wherein the polymer comprises a water soluble polymer domain with at least two hydrophobic interacting groups attached to it, and wherein the polymer is capable of assembling into a hydrogel under physiological conditions, and a physical chemical protecting group that prevents gelation of the polymer. In addition, the method involves providing a molecule that disrupts an interaction between the physical chemical protecting group and the hydrophobic interacting groups. The solution is combined with the molecule that disrupts an interaction between the physical chemical protecting group and the hydrophobic interacting groups, and prior to, during, or after this combining, the solution and the molecule that disrupts an interaction between the physical chemical protecting group and the hydrophobic interacting groups are contacted with a tissue. Finally, the solution is allowed to gel in contact with the tissue.

In a fourth aspect, the invention features a method for forming a hydrogel in contact with a tissue. The method involves providing a solution comprising a polymer, wherein the polymer comprises a water soluble polymer domain with at least two hydrophobic interacting groups attached to it, and  
5 wherein the polymer is capable of assembling into a hydrogel under physiological conditions, and a water soluble organic solvent that prevents gelation of the polymer. The method further involves removing all or part of the organic solvent from the solution, and prior to, during, or after this removal, the solution and organic solvent are contacted with a tissue. Finally, the  
10 mixture is allowed to gel in contact with the tissue.

In a fifth aspect, the invention features a method for forming a hydrogel in contact with a tissue. This method involves providing a solution comprising a polymer, wherein the polymer comprises a water soluble polymer domain with at least two hydrophobic interacting groups attached to it, and  
15 wherein the polymer is capable of assembling into a hydrogel under physiological conditions, and a water soluble organic solvent that prevents gelation of the polymer. The method also involves contacting the solution with a tissue, and allowing gelation of the mixture in contact with the tissue.

In a sixth aspect, the invention features a method for incorporating a  
20 sensitive biological material into a hydrogel composition, involving providing a solution comprising a polymer, wherein the polymer comprises a water soluble polymer domain with at least two hydrophobic interacting groups attached to it, and wherein the polymer is capable of assembling into a hydrogel under physiological conditions; and a physical chemical protecting group that  
25 prevents gelation of the polymer. The method further involves providing a molecule that disrupts an interaction between the physical chemical protecting group and the hydrophobic interacting groups, and providing a sensitive biological material. The sensitive biological material is combined with either

the solution or with the molecule that disrupts an interaction between the physical chemical protecting group and the hydrophobic interacting groups.

The solution with the molecule that disrupts an interaction between the physical chemical protecting group and the hydrophobic interacting groups and the  
5 sensitive biological material are then combined to form a mixture, and allowed to gel.

In a seventh aspect, the invention features a method for incorporating a sensitive biological material into a hydrogel composition. The method involves, providing a solution comprising a polymer, wherein the polymer  
10 comprises a water soluble polymer domain with at least two hydrophobic interacting groups attached to it, and wherein the polymer is capable of assembling into a hydrogel under physiological conditions, and an organic solvent that prevents gelation of the polymer. The method also involves providing a sensitive biological material. The sensitive biological material is  
15 combined with the solution to form a mixture, and prior to, during, or after, the combining, all or part of the organic solvent is removed from the solution. Finally, the solution is allowed to gel.

In an eighth aspect, the invention features a method for incorporating a sensitive biological material into a hydrogel composition, involving providing  
20 a solution comprising a polymer, wherein the polymer comprises a water soluble polymer domain with at least two hydrophobic interacting groups attached to it, and wherein the polymer is capable of assembling into a hydrogel under physiological conditions, and an organic solvent that prevents gelation of the polymer, and providing a sensitive biological material. The sensitive  
25 biological material is combined with the solution to form a mixture, and prior to, during, or after the combining, the solution and/or said sensitive biological material is contacted with a tissue. Gelation is then allowed to occur.



In one embodiment of the sixth or seventh or aspect of the invention, prior to gelation, the mixture is contacted with a tissue. Preferably prior to, during, or after formation of the mixture, one or more components of the mixture is contacted with a tissue.

5 In one embodiment of any of the third through eighth aspects of the invention, the polymer domain comprises poly(ethylene glycol) (PEG), poly(vinyl alcohol), poly(vinyl pyrrolidone), poly(ethyl oxazoline), poly(acrylic acid), poly(acrylamide), poly(styrene sulfonate), poly(amino acids), polysaccharides, or copolymers thereof. Preferably the polymer domain  
10 comprises poly(ethylene glycol). In another embodiment, the hydrophobic interacting groups are hydrocarbons, preferably perfluorinated hydrocarbons. Preferably the polymer domain comprises poly(ethylene glycol), the hydrophobic interacting groups are perfluorinated hydrocarbons.

In other embodiments of any of the third through eighth aspects of  
15 the invention, the polymer is linear or branched. The branched polymer may comprise a multi-arm poly(ethylene glycol). The hydrophobic interacting groups may be positioned at the termini of the polymer domain, or within the polymer domain. The linkage between the polymer domain and the hydrophobic interacting groups may be stable or degradable. Preferably the  
20 degradable linkage is an anhydride linkage, an ester linkage, a carbonate linkage, an amide linkage, or an oligomeric linkage. In a preferred embodiment, the oligomeric linkage comprises oligomers of lactic acid, glycolic acid, or epsilon-caproic acid, or oligomers of trimethylene carbonate, or co-oligomers thereof.

25 In preferred embodiments of the third or sixth aspect of the invention, the physical chemical protecting group is a molecule that covalently binds to the hydrophobic interacting group. Preferably the molecule is hydrophilic. In other embodiments, the hydrophobic interacting groups interact

with the physical chemical protecting group through a noncovalent bond.  
Preferably the interaction occurs by the formation of an inclusion complex.

In still other embodiments of the third or sixth aspects of the invention, the molecule that disrupts an interaction between the physical  
5 chemical protecting group and the hydrophobic interacting groups is a molecule that binds to the physical chemical protecting group better than the hydrophobic interacting groups bind to the physical chemical protecting group. Preferably the molecule that disrupts an interaction between the physical  
10 chemical protecting group and the hydrophobic interacting groups is a one-end modified polymer domain. Most preferably the one-end modified polymer domain comprises poly(ethylene glycol), and is modified with a perfluorinated hydrocarbon.

In still other embodiments of the third or sixth aspect of the invention, the molecule that disrupts an interaction between the physical  
15 chemical protecting group and the hydrophobic interacting groups is a molecule that degrades the linkage between the physical chemical protecting group and the hydrophobic interacting groups, or is a molecule that degrades the physical chemical interacting groups themselves. Most preferably the molecule that degrades the physical chemical interacting groups is  $\alpha$ -amylase or  
20 amyloglucosidase.

In still another preferred embodiment of the third or sixth aspect of the invention, the polymer domain comprises poly(ethylene glycol), the hydrophobic interacting groups are perfluorinated hydrocarbons, and the chemical protecting group is  $\beta$ -cyclodextrin.

25 In preferred embodiments of the fourth or seventh aspect of the invention, the organic solvent is removed by evaporating or diffusing all or part of it.

In a preferred embodiment of the fourth, fifth, seventh, or eighth aspect of the invention, the organic solvent is N-methylpyrrolidone.

By a "hydrophobic interacting group" is a group attached to the water soluble domain of a polymer, that would otherwise not be soluble under physiological conditions were it not attached to the water soluble domain of a polymer.

By a "physical chemical protecting group" is meant a group or a molecule that interacts with a hydrophobic interacting group in a manner such that the hydrophobic interacting groups are prevented from interacting with each other to an extent such that gelation occurs.

By "gelation" is meant the formation of a material into a gelled state. A material is considered to be in a gelled state when its viscosity is at least 10-fold less than its viscosity when in the presence of a physical chemical interacting group or an organic solvent that prevents the hydrophobic interacting molecules of the material from interacting to an extent such that the material is not in a liquid state.

By a "two-end modified polymer domain" is meant a polymer domain that is modified on each end to contain hydrophobic interacting groups. Preferably the polymer domain comprises PEG.

By a "one-end modified polymer domain" is meant a polymer domain that is modified on only one end to contain a hydrophobic interacting group. Preferably the polymer domain comprises PEG.

By "disrupts" is meant prevents the interaction of two molecules, for example, two hydrophobic interacting groups of a polymer. Preferably the interaction between two hydrophobic interacting groups is sufficient such that the polymer does not form a hydrogel.

As used herein, by "prevents" is meant inhibiting the interaction of hydrophobic interacting groups of a polymer in a hydrogel precursor composition, thereby inhibiting gelation of the composition. Preferably the interaction of the hydrophobic interacting groups is prevented such that the viscosity of the composition is at least 10-fold less than its viscosity when in the presence of a physical chemical protecting group or an organic solvent that inhibits the interaction of the hydrophobic interacting molecules of the material, to an extent such that the composition is not in a liquid state.

By a "stable linkage" is meant a linkage in a material that is cleaved, whether by hydrolysis or oxidation, at a rate slower than the rest of the material is degraded, or otherwise cleared from a site or the body.

By a "stable linkage" is meant a linkage in a material that is cleaved, whether by hydrolysis or oxidation, at a rate that is faster than the rest of the material is degraded or otherwise cleared from a site or the body. The degradation of an unstable linkage determines, at least in part, the overall rate of degradation of the material or its clearance from a site or the body.

By an "inclusion complex" is meant a complex between two components. As used herein, an inclusion complex is formed between a hydrophobic interacting group(s) and a physical protecting group, such that the one component (the hydrophobic interacting group) is partially or wholly surrounded by the second component (the physical chemical protecting group).

By a "sensitive biological material" is meant a material that has biological activity. A sensitive biological material may include, for example, peptides, polypeptides, proteins, synthetic organic molecules, naturally occurring organic molecules, nucleic acid molecules, carbohydrates, lipids, cells, tissues, tissue or cell aggregates, and components thereof.

### Brief Description of the Drawings

Fig. 1 is a graph illustrating the storage modulus of gel phases in equilibrium at 298°K.

Fig. 2 is graph illustrating the loss modulus of gel phases in  
5 equilibrium at 298°K.

Fig. 3 is a graph illustrating the viscosity change of 10KC8 in aqueous solution, induced by addition of N-methylpyrrolidone (NMP) to disrupt the association of 10KC8.

Fig. 4 is a graph illustrating the re-establishment of the associated  
10 state of 10KC8 by solvent exchange, from NMP to water.

### Detailed Description

The present invention features hydrogels formed by the physical association of polymers in a hydrogel precursor composition. The hydrogel may comprise any hydrophilic (soluble) and biocompatible polymer domain,  
15 modified with any hydrophobic interacting groups at two or more sites along the chain (e.g., at the ends or in the domain of the polymer). These hydrophobic interacting groups bind strongly to each other in an interchain manner to form a gel matrix *in situ*.

An injectable state of the polymer matrix is produced either by the  
20 addition of molecules termed "physical chemical protecting groups" that act to disrupt association among the hydrophobic interacting groups of the polymer matrix, or by changing the solvent state to disrupt association among the hydrophobic interacting groups of the polymer matrix.

The injectable state of the hydrogel precursor composition can be  
25 switched to a solid hydrogel state by removal of the physical chemical protecting groups after or during delivery to the desired site so that association among the hydrophobic interacting groups is re-established. The physical

chemical protecting groups may be removed by their degradation, using, for example, an enzyme, or by addition of a competitor that binds the physical chemical protecting groups, transferring them away from the association sites of the polymer matrix. A PEG molecule with one end modified with a  
5 hydrophobic interacting group is one example of a competitor that may be used. The physical chemical protecting groups may also be removed by disrupting the bonds formed between the hydrophobic interacting groups and the physical chemical protecting groups.

The injectable state of the hydrogel precursor composition can also  
10 be switched to a solid hydrogel state by changing the solvent conditions to replace a solvent that does not permit association of the hydrophobic interacting groups with a solution that does permit such association. For example, an organic solvent, such as N-methylpyrrolidone (NMP) does not permit association of the hydrophobic interacting groups, but replacing the  
15 solvent with an aqueous solution, for example that of a tissue or other body fluid, or evaporating the organic solvent off does permit association.

This novel approach to making polymeric compositions that transition from a liquid state to a solid state is advantageous for the following reasons. It is safe and economical, because it does not involve chemical  
20 reactions or the transfer of heat, and it does not require the use of complex instruments and surgical devices that supply both fluids and light to a site. In addition, the hydrogel precursor composition may be applied to a site, for example, a tissue, and formed to the morphology of the site. Another advantage of this method is that a large amount of material may be delivered to  
25 a site using minimally invasive surgery, because the material is in a liquid, injectable state.

### **Polymer Domains**

Any polymer domain that is substantially water-soluble may be used in the present invention. Examples of such polymer domains include, but are not limited to, poly(ethylene glycol), poly(vinyl alcohol), poly(vinyl pyrrolidone), poly(ethyl oxazoline), poly(acrylic acid), poly(acrylamide),  
5 poly(styrene sulfonate), poly(amino acids), polysaccharides, and copolymers thereof. Each of these polymers presents numerous opportunities for attachment of the hydrophobic interacting groups. For example, initiation and termination of polymerization can be performed so as to obtain good control  
10 over the identity of polymer end groups, allowing the hydrophobic interacting groups to be attached thereto.

Alternatively, the hydrophobic interacting groups can be attached as side groups on the polymer domain, either directly by coupling to the side group on the polymer domain (e.g., coupling to the carboxylic acid side groups  
15 on poly(acrylic acid)) or indirectly, by coupling to side groups incorporated into the polymer domain by copolymerization (e.g., coupling to carboxylic acid side groups on poly(acrylamide-co-acrylic acid)). For use in the present invention, PEG homopolymers that are approximately 4,000 to 10,000 g/mol are particularly useful.

### **Hydrophobic interacting groups**

Perfluorinated hydrocarbons are the hydrophobic interacting groups that provide for the desired gelation transitions. Preferably the perfluorinated hydrocarbons have the formula  $C_nF_{2n+1}CH_2CH_2OH$ , where  $n=6$  to  $10$ . Other hydrocarbon groups can also provide these desired gelation interactions, and  
25 may be used, although they interact with less affinity than the corresponding perfluorinated hydrocarbon groups.

### **Connecting schemes between the polymer and the hydrophobic interacting groups**

- The linkage between the hydrophobic interacting groups and the polymer domain may be selected to be relatively stable or readily degradable.
- 5 For example, the hydrophobic interacting groups can be attached via anhydride, ester, carbonate, or amide linkages, to make them susceptible to hydrolysis. Oligomeric linkages (e.g. oligomers of lactic, glycolic, or epsilon-caproic acid or oligomers of trimethylene carbonate) can also be incorporated between the polymer chain and the hydrophobic interacting groups. This allows for the
- 10 regulation of degradation by a process that is hydrolytically controlled. Also, the design and incorporation of such degradable linkages will lead to more predictable toxicology and pathways for elimination of the polymer from the body.

### **Polymer conformations**

- 15 The polymers of the present invention may be linear or branched. A branched conformation may lead to more effective gel formation due to the existence of multiple points for interaction. Thus, multi-arm PEGs (e.g., those PEGs having more than 2 arms) are effective polymer domains. Even more complex branching can be included in the polymer conformations of the
- 20 invention. The polymers of the present invention may possess terminal hydrophobic interacting groups or the hydrophobic interacting groups may be incorporated along the polymer domain, either by copolymerization or by copolymerization of a site for secondary grafting of the hydrophobic interacting group. Incorporation of hydrophobic interacting groups along the polymer
- 25 domain provides for a greater density of hydrophobic interacting groups.



### **Physical chemical protecting groups**

The physical chemical protecting groups may interact with the hydrophobic interacting groups in various ways. For example, the physical chemical protecting groups and the hydrophobic interacting groups may exist  
5 as an inclusion complex. Examples of physical chemical protecting groups include, but are not limited to, cyclodextrins, for example,  $\alpha$ -,  $\beta$ -, or  $\gamma$ -cyclodextrin. The physical chemical protecting group may be removed by an enzyme, for example, a cyclodextrinase, thus exposing the hydrophobic interacting groups .

10 Alternatively, a hydrophilic bulky group (the physical chemical protecting group) can be attached beside or on the terminus of the hydrophobic interacting group, with a hydrolytically sensitive linkage. Rapid hydrolysis then triggers a transition from the sol (soluble state) to the gel state. Such a hydrophilic group may be a PEG chain, for example, and the linkage may be a  
15 hydrolytically sensitive ester anhydride, amide, carbonate, or oligomeric linkage. This linkage may also be an enzymatically cleavable site, which results in degradation (and thus gelation) after addition of the appropriate enzyme.

### **Solvents that prevent interactions between hydrophobic interacting groups**

20 Organic solvents may be used to prevent hydrophobic interacting groups from associating, thus prevent gel formation. The injectable state of the hydrogel precursor composition can be switched to a solid hydrogel state by changing the solvent conditions to replace a solvent that does not permit association of the hydrophobic interacting groups with a solution that does  
25 permit such association. For example, an organic solvent, such as N-methylpyrrolidone (NMP) does not permit association of the hydrophobic interacting groups. But replacing the organic solvent with an aqueous solution,

including that of a tissue or other body fluid, or evaporating the organic solvent off does permit association of the hydrophobic interacting groups. When the solvent exchange is done *in vivo*, the preferred solvent is NMP (because of the low toxicity). When *in vitro* solvent exchange is conducted, a number of  
5 organic solvents may be used, including, for example, ethyl acetate. Such the solvents may be removed prior to introduction of the hydrogel to an *in vivo* site.

Alternatively, the organic solvent may be removed by evaporation, thus allowing the precursor hydrogel solution to form a hydrogel. For example, the organic solvent may be evaporated from a solution of polymer and NMP or  
10 methylene chloride, resulting in formation of a polymer matrix. Then the polymer matrix may be rehydrated in water, either *in vitro* or *in vivo*.

#### **Hydrogels in contact with tissues**

The hydrogels of the present invention may be formed in contact with a tissue. Preferably the tissue is within a tumor, subcutaneous,  
15 intramuscular, adjacent to a tooth, upon the inner or outer surface of an artery or vascular graft, or upon any tissue surface when used to prevent postoperative adhesions.

#### **Incorporation of a sensitive biological material**

A sensitive biological material may be incorporated into a hydrogel  
20 through the practice of this invention. Examples of sensitive biological materials include, but are not limited to drugs, proteins, peptides, RNA, DNA, inorganic and organic molecules, carbohydrates, lipids, cells, tissues, tissue or cell aggregates, and combinations thereof.

Specific examples of cells that may be incorporated into the hydrogel  
25 include, but are not limited to, chondrocytes, endothelial cells, muscle cells, fibroblasts, skin cells, islets of Langerhans, and genetically modified cells for

protein delivery.

Specific examples of sensitive biological materials that may be incorporated into the hydrogels include, enzymes, antibiotics, antineoplastic agents, local anesthetics, hormones, antiangiogenic agents, antibodies, 5 neurotransmitters, psychoactive drugs, drugs affecting reproductive organs, oligonucleotides, including antisense oligonucleotides, vasoactive agents, anticoagulants, immunomodulators, cytotoxic agents, antiviral agents, and combinations thereof.

Exemplary sensitive biologicals materials which may be 10 incorporated into the hydrogels of the present invention include growth hormone, for example, human growth hormone, calcitonin, granulocyte macrophage colony stimulating factor (GM-CSF), ciliary neurotrophic factor, and parathyroid hormone. Other specific therapeutic agents include parathyroid hormone-related polypeptide, somatostatin, testosterone, 15 progesterone, estradiol, nicotine, fentanyl, norethisterone, clonidine, scopolamine, salicylate, salmeterol, formoterol, albuterol, and valium.

Drugs for the treatment of pneumonia may be used, including pentamidine isothionate. Drugs for the treatment of pulmonary conditions, such as asthma may be used, including albuterol sulfate,  $\beta$ -agonists, 20 metaproterenol sulfate, beclomethasone dipropionate, triamcinolone acetamide, budesonide acetonide, ipratropium bromide, flunisolide, cromolyn sodium, ergotamine tartrate, and protein or polypeptide drugs such as TNF antagonists or interleukin antagonists.

Other therapeutic agents include cancer chemotherapeutic agents, 25 such as cytokines, chemokines, lymphokines, and substantially purified nucleic acids, and vaccines, such as attenuated influenza virus. Substantially purified nucleic acids that can be incorporated include genomic nucleic acid sequences, cDNAs encoding proteins, expression vectors, antisense molecules that bind to

complementary nucleic acid sequences to inhibit transcription or translation, and ribozymes. For example, genes for the treatment of diseases such as cystic fibrosis, for example, cystic fibrosis transmembrane regulator can be administered. Polysaccharides, such as heparin, can also be administered.

5 Further therapeutic agents include tissue plasminogen activator (t-PA), superoxide dismutase, catalase luteinizing hormone releasing hormone (LHRH) antagonists, IL-11 platelet factor, IL-4 receptor, enbrel, IL-1 receptor antagonists, TNF receptor fusion proteins, megakaryocyte growth and development factor (MGDF), stemgen, anti-HER-2 and anti-VEGF humanized  
10 monoclonal antibody, anti-Tac antibody, GLP-1 amylin, and GLP-1 amylin analogues.

Additional therapeutic agents include atrial natriuretic factor, atrial natriuretic peptide, beta-human chorionic gonadotropin, basic fibroblast growth factor, bovine growth hormone, bone morphogenetic protein, B cell stimulating  
15 factor-1, B cell stimulating factor-2, bovine somatotropin, carcinobreaking factor, cartilage induction factor, corticotropin releasing factor, colony stimulating factor, differentiating factor-1, endothelial cell growth factor, erythroid differentiation factor, elongation factor 1-alpha, epidermal growth factor, erythropoietin, thrombopoietin, thymopoietin, fibroblast growth factor,  
20 follicle stimulating hormone, granulocyte colony stimulating factor, glial fibrillary acidic protein, growth hormone releasing factor, human alpha-1 antitrypsin, human atrial natriuretic factor, human chorionic gonadotropin, human leukemia inhibitory factor, hemopoietin-1, hepatocyte growth factor, human transforming growth factor, human thyroid-stimulating hormone,  
25 interferon, immunoglobulin A, immunoglobulin D, immunoglobulin E, insulin-like growth factor-1, insulin-like growth factor-II, immunoglobulin G, immunoglobulin M, interleukin-1, interleukin-2, interleukin-3, interleukin-4, interleukin-5, interleukin-6, kidney plasminogen activator, lectin cell adhesion

- molecule, luteinizing hormone, leukemia inhibitor factor, monoclonal antibody, macrophage activating factor, macrophage cytotoxic factor, macrophage colony stimulating factor, megakaryocyte colony stimulating factor, tumor necrosis factor, macrophage inhibitory factor, Mullerian inhibiting substance,
- 5 megakaryocyte stimulating factor, melanocyte stimulating factor, neutrophil chemotactic factor, nerve growth factor, novel plasminogen activator, nonsteroidal anti-inflammatory drug, osteogenic factor extract, antitumor lymphokine, prostate-specific antigen, anti-platelet activating factor, plasminogen activator inhibitor, platelet-derived growth factor, platelet-derived
- 10 wound healing formula, plasmatic human interleukin inducing protein, tumor angiogenesis factor, tissue control factor, T cell growth factor, T cell modulatory peptide, transforming growth factor, tumor growth inhibitor, tumor inhibiting factor, tissue inhibitor of metalloproteinases, tumor necrosis factor, tissue plasminogen activator, thyroid stimulating hormone, urokinase-
- 15 plasminogen activator, vascular endothelial growth factor, and vasoactive intestinal peptide.

Drugs may be dissolved or suspended as precipitates within the polymer form in its dissociated state. This dissociated state can be converted into the associated hydrogel state by any of the methods described above, e.g.,

20 by solvent exchange, by drying, by degradation of a protecting group, or by competitive displacement of a protecting group.

As a specific example, the associating polymers are dissolved in dichloromethane at about 40% by weight and a protein drug is added as a suspension. The solution is dried by evaporation to form a film or particles.

25 The dry polymer-protein depot is then re-hydrated by addition of a limited amount of buffered saline (e.g., an amount necessary to bring the material to its equilibrium swelling state). The material is injected, for example, as a particulate, or placed in a tissue site to release its drug.

As a second specific example, the associating polymers are dissolved in NMP at about 50% by weight and the protein is added as a suspension. The polymer-protein-NMP mixture is injected into a tissue site, whereupon diffusion of the NMP from the system and counter-diffusion of water into the system results in a swollen gel depot. Alternatively, the NMP is exchanged against water away from a tissue site, to produce a swollen material that is then injected as a particulate, or placed in a tissue site.

In both of the above examples, the protein is released by diffusion from the depot, with some contribution to the release process also being given by dissolution of the material from the surface of the depot.

#### **Example 1: Synthesis of end-group modified PEGs**

Poly (ethylene glycol) (PEG) of nominal molecular weight 6000 g/mol (6K) (from Fluka), 10K (from Aldrich), and 20K (from Fluka) were used. Three different fluorinated alcohols ( $C_nF_{2n+1}CH_2CH_2OH$ , where  $n = 6, 8, 10$ ) were purchased from Lancaster Synthesis Inc. Isophorone diisocyanate (IPDI), dibutyltin diacetate and anhydrous tetrahydrofuran (THF) were purchased from Aldrich.

The method of Glass et al. (Kaczmarek and Glass, *Macromolecules*, 26:5149-5156, 1993) was used to attach the perfluorinated end groups to the terminal hydroxyls of PEG. PEG was dried by azeotropic distillation in toluene, and was reacted with 100 fold molar excess (with respect to end-groups) of vacuum-distilled IPDI in anhydrous THF for 48 hours. This intermediate was precipitated in anhydrous ethyl ether to remove unreacted IPDI, and was subsequently reacted with a 10-fold excess of perfluoroalcohol in anhydrous THF for 48 hours. Dibutyltin diacetate was added for the second step. The reaction mixture was precipitated in anhydrous ethyl ether, then dissolved in THF, and reprecipitated to form the final two-end modified PEG

molecules that contain hydrophobic interacting groups. All reactions were done under argon purge.

One-end modified PEG molecules can be generated using a monomethoxy PEG, and keeping the molar ratios in the reaction the same as those described above.

The degree of substitution was determined by  $^{19}\text{F}$  NMR using  $\text{CF}_3\text{COOH}$  or  $\text{CF}_3\text{SO}_3\text{Na}$  as an internal standard with a 5 second delay time (i.e., long enough to get the integral value independent of the delay time between pulses). The samples prepared for this study are described in Table 1, where nKCm is the sample, in which nK denotes the PEG molecular weight and Cm denotes the length of the  $\text{C}_m\text{F}_{2m+1}\text{CH}_2\text{CH}_2\text{OH}$  group.

For a given PEG, each sample modified with  $\text{C}_{10}\text{F}_{21}$  was checked by reverse phase HPLC. A C18 column was used with the Water HPLC system with a gradient input of mixed solvent (ranging from 20:80 of acetonitrile:ethanol to 100% acetonitrile) that can separate unmodified, one-end modified, and two-end modified samples. Good agreement between the values obtained by HPLC (in parenthesis in the final column of Table 1) and the values obtained by  $^{19}\text{F}$  NMR support the reliability of the NMR method.

**Table 1. Reaction extent of two-end modified PEGs**

Sample	PEG-block	End-group	Degree of substitution (%)
6KC10	6 kg/mol	$-(\text{CH}_2)_2-\text{C}_{10}\text{F}_{21}$	97 (97)
6kC8	6 kg/mol	$-(\text{CH}_2)_2-\text{C}_8\text{F}_{17}$	89
6KC6	6 kg/mol	$-(\text{CH}_2)_2-\text{C}_6\text{F}_{13}$	99
10KC10	10 kg/mol	$-(\text{CH}_2)_2-\text{C}_{10}\text{F}_{21}$	94 (96)
10KC8	10 kg/mol	$-(\text{CH}_2)_2-\text{C}_8\text{F}_{17}$	94
20KC10	20 kg/mol	$-(\text{CH}_2)_2-\text{C}_{10}\text{F}_{21}$	97 (92)
20KC8	20 kg/mol	$-(\text{CH}_2)_2-\text{C}_8\text{F}_{17}$	96

**Example 2: Formation of hydrogel phases**

The phase behavior of two-end modified PEGs was governed by the relative length of the PEG chain and the perfluorinated hydrocarbon end groups (Table 2). Some of the two-end modified PEGs showed phase separation and others did not. This phase separation phenomenon can provide useful applications for these transition systems; when this system is used as a delivery device in the open system, it will maintain the high modulus matrix of the equilibrium composition, compared to the systems using materials which do not show the phase separation, since the matrix formed from these would be dissolved with continuous lowering of the modulus for the same concentration of polymers.

Among the two-end modified PEGs synthesized, 6KC10 did not exist as a homogeneous phase in water, rather only as a slightly swollen precipitate. At the other extreme, 20KC10 and 20KC8 existed as homogeneous solutions over the whole range of polymer concentrations, though the viscosity increased drastically as the concentration of polymer increased. Polymers that were in between 6KC10 and 20KC8 in terms of the relative length of PEG to the hydrophobic end groups, for example, 6KC6, 6KC8, 10KC8, and 10KC10, showed phase separation into a gel coexisting with a sol (soluble liquid phase) in water and in phosphate buffered saline (PBS) solution. Increasing the temperature did not lead to any noticeable change of the gel phase concentration for the phase separating systems; the phase boundary was almost temperature-invariant. But, some increase of the gel phase concentration was observed for 10KC8 above 60 °C.

The gel properties, such as modulus and transport properties (diffusion coefficient and viscosity) were sensitive to the degree of swelling of the gel (the inverse of the gel phase concentration). Increasing the length of the PEG chain increased the swelling ratio of the gel, since it is analogous to



reducing the crosslink density. When the PEG length was fixed and the length of the hydrophobic interacting group was varied, the swelling ratio was nearly constant (compare 10KC10 to 10KC8; and compare 6KC8 to 6KC6). The swelling ratio increased, however, with PEG length (compare 6KC8 to  
5 10KC8).

The low concentration of the dilute phase (sol phase) means that a small driving force for the degradation of these gels would be present when they are exposed to an open system (e.g., as an implant) in the case of diffusion in the dilute phase to be rate-determining step, compared to the systems which  
10 do not show phase separation for the same concentration of polymers.

The behavior of the polymers in deionized water versus phosphate buffered saline (PBS) showed that the gel concentration was slightly higher in PBS than in water, and the sol concentration was consistently lower in PBS than in water. This difference was due to the decrease of solvation of PEG  
15 chains from a salting out effect and the increase of aggregation tendency of fluorocarbon end groups by the added salts in the PBS solution (Zhang et al, Abstract of the American Chemical Society Meeting, 213, 236, 1997; and Bailey et al., J. Appl. Polym. Sci. 1:56-62, 1959). The effect of dissolved electrolytes will be present *in vivo*, with the beneficial effects of increasing the  
20 modulus and reducing the rate of dissolution.

Table 2. Phase behaviors and compositions of phases of modified PEGs

	sample in PBS (wt%)	type of phase behavior	equilibrium compositions in water (wt%)		equilibrium compositions in PBS (wt%)	
			gel conc., $C_{gel, eq}$	sol conc., $C_{sol, eq}$	gel conc., $C_{gel, eq}$	sol conc., $C_{sol, eq}$
5	20KC8	1 phase	N/A	N/A	N/A	N/A
	20K10	1 phase	N/A	N/A	N/A	N/A
	10KC8	2 phase	6.5±0.2	0.075±0.005	7.8±0.2	0.055±0.002
	10KC10	2 phase	6.8±0.7	0.019±0.008	8.1±0.7	0.011±0.003
	6KC6	2 phase	9.5±0.5	0.066±0.007	10.5±0.6	0.038±0.002
10	6KC8	2 phase	11.0±0.3	0.042±0.007	12.5±0.3	0.017±0.001
	6KC10	insoluble	N/A	N/A	N/A	N/A

**Example 3: Rheological properties of gel phases**

Rheological measurements were made to gain initial insight into gel structure (Table 3). Previous work by Annable, et al., (J. Rheology 37:695-726, 1993) showed that the PEG systems modified with hydrocarbon tails were governed by a single relaxation time. Thus, these systems can be well described by a simple Maxwell model.

The gel phases of all the systems showing phase separations were still governed by the single relaxation behavior. A similar order of magnitude of infinite modulus ( $G_{\infty}$ ,  $10^4$  Pa) was observed for 10KC10 and 10KC8, indicating the similar density of physical junctions within these two gels, which

coincide with similar values of swelling ratios. A higher value was observed for 6KC8, meaning a higher density of physical junctions was present, which also agrees with the smaller swelling ratio. The large difference in relaxation time between 10KC10 and 10KC8 showed that the addition of one  $\text{CF}_2$  unit  
 5 significantly increases the strength of physical junctions, resulting in a longer relaxation time.

**Table 3. Relaxation times of gel phases in equilibrium at 298K**

	10KC10	10KC8	6KC8
Relaxation time (sec)	1.14	0.028	0.021

**Example 4: Disruption of a gel by  $\beta$ -CD (induction to the injectable state)**

10 Cyclodextrins (CDs) are cyclic starches consisting of 6, 7, or 8  $\alpha$ -1,4-linked glucose monomers called  $\alpha$ ,  $\beta$ , and  $\gamma$  - cyclodextrin, respectively. These molecules are ring or torus-shaped and possess a hydrophobic cavity and a hydrophilic exterior. The partial hydrophobic nature of CD allows it to associate with nonpolar organic moieties or molecules to form inclusion  
 15 complexes (Shieh et al., Pure Appl. Chem. A33:673-683, 1996).

Complex formation between  $\alpha$ ,  $\beta$ , and  $\gamma$ - CD and perfluorocarbon surfactants showed that  $\beta$ -CD has the largest association constants among the cyclodextrins for a given hydrophilic head. For long fluorocarbon surfactants ( $\text{C}_m\text{F}_{2m+1}\text{Na}$ , where  $m \geq 7$ ), it is even possible for two  $\beta$ -CD molecules to bind to  
 20 each surfactant molecule (Guo et al., Langmuir 8:446-451, 1992). Based on the association between  $\beta$ -CD and the fluorocarbon surfactants, the addition of  $\beta$ -CD to solutions of one end-modified PEG (modified with perfluorinated groups) reduced the viscosity of the solution (Zhang, et al., Abstract of the American Chemical Society Meeting, 211:166-Poly, 1996).

If the complexation of  $\beta$ -CD to the fluoro end groups of two-end modified PEG is sufficient to hide the hydrophobicity of the end groups, the gel phase will not be formed. Mixing a saturated aqueous solution of  $\beta$ -CD and the gel phase of 10KC10 caused the disappearance of the gel-phase. In addition, 5 adding a one-fold molar ratio excess of  $\beta$ -CD to end groups to 10KC10, applying water, and shaking the solution resulted in low viscosity solutions. These results indicated that  $\beta$ -CD can effectively prevent the hydrophobic interacting groups of the polymer from strongly associating with each. The solution was not clear, especially for the higher concentration of solutes, and 10 the apparent viscosity was much higher than the same concentration of unmodified pure PEG solution, so it appears that there may be weak or local associations among the  $\beta$ -CD-complexed polymers. Nevertheless, the addition of cyclodextrin to the polymers is enough to transition the gel to an injectable state.

#### 15 **Example 5: Reformation of a gel by enzymatic degradation of $\beta$ -CD**

There are several sources of enzymes that can degrade cyclodextrin. Most of them are from microbial sources, but enzymes from saliva and the pancreas can also effectively degrade  $\gamma$ -CD and to a lesser extent  $\beta$ -CD (Saha et al., Starch/Stärke 44:312-315, 1992).  $\alpha$ -amylase from aspergillus oryzae can 20 degrade  $\beta$ -CD (Jordal et al, Starch/Stärke 36:104-143, 1984), although it is a relatively poor cyclodextrinase.

Two enzymes were tested for their ability to degrade cyclodextrin in the system described herein:  $\alpha$ -amylase from aspergillus oryzae (crude powder), and amyloglucosidase from aspergillus niger (solution in 1 M 25 glucose), both purchased from Sigma. In one study, 0.008 g of  $\alpha$ -amylase (from aspergillus oryzae) was added to 0.55 g of the homogeneous complex solution of 10KC8 and  $\beta$ -CD (7.73 weight % for 10KC8, and 3.35 weight % for

$\beta$ -CD). After shaking to mix, the sample was kept at 37 °C. The sample started to become viscous upon mixing, and after 20 minutes, it exhibited a gel-like structure.

In a second study, 0.065 g of the enzyme solution amyloglucosidase  
5 (from aspergillus niger) was added to 0.513 g of the precursor solution (7.59 weight % for 10KC8, and 3.27 weight % for  $\beta$ -CD). After 30 minutes, the sample started to become viscous, and after 70 minutes, it became insoluble.

**Example 6: Reformation of a gel by transfer of CD to a one-end modified PEG**

10 PEGs modified to contain a hydrophobic interacting group on only one end will form a micelle-like structure in aqueous solutions, and in this structure they are injectable even when present below the critical transition concentration. Furthermore, the affinity of a one-end modified PEG having a small molecular weight of a PEG for CD is greater than the affinity of a two-  
15 end modified PEG having a large molecular weight of PEG for CD (Amiel et al., J. Inclusion Phen. & Mol. Recog., 25:61-67, 1996). Thus, mixing a CD-complexed, two-end modified PEG solution and an appropriate amount of a one-end modified PEG solution will result in the transfer of the majority of  $\beta$ -CD from the two-end modified PEG to the one-end modified PEG by mass  
20 action and the higher tendency to make inclusion complexes with the one-end PEG. The removal of  $\beta$ -CD from the two-end modified PEG then reveals the hydrophobic interacting groups of the two-end modified PEGs, and, if the concentration of the added one-end modified PEG is not so high as to break down the physical junction by the surfactant action of the excess bare one-end  
25 modified PEG, the mixture will form a gel structure again.

With 10KC10 as a gel-forming agent, 5K-M-C10 and 2K-M-C10 (where M denotes that only one end is modified with a perfluorinated group)

were explored as CD-transfer inducing agents. First, a 5 weight % solution of 10KC10, coupled with CDs, and a 10.2 weight % solution of 5K-M-C10 solution were mixed together in equal amounts. The mixture exhibited a marked enhancement of viscosity, but did not form a gel state (where the gel state was determined by whether there was a noticeable flow of solution when the vial containing it was inverted).

Next, using 2K-M-C10 and 10KC10, the mixing ratios were varied from 1:1 to 1:3 (10KC10:2K-M-C10, in molar concentration), keeping the total concentrations of the reactants constant at 6.3 weight %. Among these mixtures, the 1:2 ratio gave the most gel-like state, which was maintained up to a temperature of 37 °C. A 1:2 molar ratio mixture of 10KC10-CD complex solution (0.073 g/ml, polymer/water) and 18.2 weight % of 2K-M-C10 solution resulted in reversion to a gel structure. For 10KC8, a 1:1 molar ratio was sufficient to induce the gel phase since CD transfers more easily from the C8 end group of the two-end modified PEG to the C10 end group of the one-end modified PEG.

#### **Example 7: Dissolution characteristics of gel phases**

Dissolution rates of gel phases are measured by direct measurements of dissolved amounts of polymers, or by the shift of the surface plasmon resonance angle of ultrathin gold film coated with the thin film of the polymer matrix that is exposed to the flow of water (Aust et al., TIP 2:313-32, 1994). For the transition system showing phase separations, the compositions of the polymer matrix are the equilibrium gel concentrations. To compare the phase separation system with the system with no phase separation, the dissolution rates of 10 weight % of 20KC10 and 12.8 weight % of one-end modified 5K-M-C10, which shows a lyotropic gel phase transition at that concentration, were measured (Table 4).

**Table 4. Dissolution rates of polymer matrix**

	10KC10	10KC8	6KC8	20KC10	5K-M-C10
<b>Conc. (wt %)</b>	(6.8 wt %)	(6.5 wt %)	(11.0 wt %)	(10.0 wt %)	(12.8 wt %)
<b>Dissolution rate (mg/cm<sup>2</sup>/hr)</b>	not measurable	$1.67 \times 10^{-3}$	$3.33 \times 10^{-4}$	0.168	0.201

- As expected, the systems which did not show phase separation (20KC10 and 5K-M-C10) exhibited much faster dissolution rates than those with phase-separation (~ 100 times faster rates of 20KC10 than that of 10KC8).
- 10 Of the phase-separating systems examined, 6KC8 showed around 5 times slower dissolution rates than 10KC8, and the rate of 10KC10 dissolution was much slower than 6KC8. The absolute small value of dissolution rates for the phase separating species confirmed that these species can be used as delivery carriers in the open system. Also, by choosing the right ratio of hydrophilic and hydrophobic groups, the degradation rate of the matrix can be controlled.

- Another feature of polymer matrix degradation is whether the matrix is degraded homogeneously or heterogeneously. Maintaining the constant resonance angle for the phase separating species until the film is thin enough so that the thickness affects the resonance angle denotes that no change in the refractive index of the polymer matrix. This means that the hydrogels degrade heterogeneously (i.e., from the surface inward). Such a heterogeneous degradation characteristic is beneficial for the application of delivery of a sensitive biological material, because the drug can exhibit a liner (i.e., zero order) release profile. Thus using the systems of this invention, the constant release of a drug is achievable.

**Example 8: Disruption of a gel by addition of organic solvents**

- Associative interactions of polymers through their hydrophobic interacting groups may be disrupted by altering the characteristics of the solvent that the polymers are contained in, and these interactions may be re-
- 5 established by altering the solvent again. Disrupting the associative interactions of the polymer can be achieved, for example, by dissolving the gel-forming polymer in a water mixture with a water-soluble organic solvent, such as NMP, or in the organic solvent neat, and then converting the non-associative state into the associated state by removal of the solvent and addition of water.
- 10 This may be accomplished in a number of ways. A flowable solution of the polymer in NMP or an NMP-water mixture (in the non-associated state) may be contacted with an aqueous environment, permitting the diffusion of the NMP from the polymer solution and its corresponding replacement by water, thus converting the material into an associative state.
- 15 Alternatively, the material in the NMP or NMP-water mixture may be injected into a tissue site, and the NMP allowed to exchange with the aqueous component of the body fluids, to achieve the same end. When the exchange is conducted *in vivo*, the preferred solvent is NMP, the toxicity of which is very low, although other solvents, including ethyl acetate, may also be
- 20 useful. When the exchange is conducted *in vitro*, for example, for the encapsulation of drugs, a wide variety of solvents are available, since the solvent may be removed before introduction into the body. Alternatively, the solvent may be removed by evaporation, such as by drying a solution of the polymer from NMP or methylene chloride, followed by rehydration in water,
- 25 either *in vitro* or *in vivo*.

As evidence that the associated state may be disrupted by the addition of an organic solvent, the viscosity of a 8% solution of 10KC8 in water was measured. Varying concentrations of NMP were added to this



solution, and a dramatic reduction in the viscosity of the system was observed, as illustrated in Figure 3.

As evidence that the associated state may be restored by the exchange of an organic solvent, a 50% solution of 10KC8 in NMP was placed  
5 within a reservoir of water, the thickness of the initial sample was approximately 1.5 mm. For this system, the steady viscosity of the sample increased dramatically by more than two orders of magnitude, as shown in Figure 4.

All publications mentioned in this specification are herein  
10 incorporated by reference to the same extent as if each independent publication or patent application was specifically and individually indicated to be incorporated by reference.

What is claimed is:

1. A hydrogel precursor composition comprising:
  - (a) a polymer, said polymer comprising a water soluble polymer domain with at least two hydrophobic interacting groups attached thereto, said  
5 polymer capable of assembling into a hydrogel under physiological conditions;  
and
  - (b) a physical chemical protecting group, said physical chemical protecting group preventing gelation of said hydrogel precursor composition.
2. A hydrogel or hydrogel precursor composition comprising:
  - 10 (a) a polymer, said polymer comprising a water soluble polymer domain with at least two hydrophobic interacting groups attached thereto, said polymer capable of assembling into a hydrogel under physiological conditions;  
(b) a physical chemical protecting group, said physical chemical protecting group preventing gelation of said hydrogel precursor composition or  
15 hydrogel; and
  - (c) a molecule that disrupts an interaction between said physical chemical protecting group and said hydrophobic interacting groups.
3. The hydrogel or hydrogel precursor composition of claim 1 or 2,  
wherein said polymer domain comprises poly(ethylene glycol), poly(vinyl  
20 alcohol), poly(vinyl pyrrolidone), poly(ethyl oxazoline), poly(acrylic acid),  
poly(acrylamide), poly(styrene sulfonate), poly(amino acids), polysaccharides,  
or copolymers thereof.
4. The hydrogel or hydrogel precursor composition of claim 3,  
wherein said polymer domain comprises poly(ethylene glycol).

5. The hydrogel or hydrogel precursor composition of claim 1 or 2,  
wherein said hydrophobic interacting groups are hydrocarbons.
6. The hydrogel or hydrogel precursor composition of claim 5,  
5 wherein said hydrocarbons are perfluorinated hydrocarbons.
7. The hydrogel or hydrogel precursor composition of claim 1 or 2,  
wherein said physical chemical protecting group is a cyclodextrin.
8. The hydrogel or hydrogel precursor composition of claim 7,  
wherein said cyclodextrin is  $\beta$ -cyclodextrin.
- 10 9. The hydrogel or hydrogel precursor composition of claim 1 or 2,  
wherein said physical chemical protecting group is a molecule that covalently  
binds to said hydrophobic interacting groups.
10. The hydrogel or hydrogel precursor composition of claim 9,  
wherein said molecule that covalently binds to said hydrophobic interacting  
15 groups is hydrophilic.
11. The hydrogel or hydrogel precursor composition of claim 1 or 2,  
wherein said polymer domain comprises poly(ethylene glycol) and said  
hydrophobic interacting groups are perfluorinated hydrocarbons.
12. The hydrogel or hydrogel precursor composition of claim 11,  
20 wherein said chemical protecting group is  $\beta$ -cyclodextrin.

13. The hydrogel or hydrogel precursor composition of claim 1 or 2,  
wherein said polymer is linear.

14. The hydrogel or hydrogel precursor composition of claim 1 or 2,  
5 wherein said polymer is branched.

15. The hydrogel or hydrogel precursor composition of claim 14,  
wherein said polymer domain comprises multi-arm poly(ethylene glycol).

16. The hydrogel or hydrogel precursor composition of claim 1 or 2,  
wherein said hydrophobic interacting groups are positioned at the termini of  
10 said polymer domain.

17. The hydrogel or hydrogel precursor composition of claim 1 or 2,  
wherein said hydrophobic interacting groups are positioned within said  
polymer domain.

18. The hydrogel or hydrogel precursor composition of claim 1 or 2,  
15 wherein the linkage between said polymer domain and said hydrophobic  
interacting groups is stable.

19. The hydrogel or hydrogel precursor composition of claim 1 or 2,  
wherein the linkage between said polymer domain and said hydrophobic  
interacting groups is degradable.

20

20. The hydrogel or hydrogel precursor composition of claim 19, wherein said degradable linkage is selected from the group consisting of an anhydride linkage, an ester linkage, a carbonate linkage, an amide linkage, and an oligomeric linkage.

5           21. The hydrogel or hydrogel precursor composition of claim 20, wherein said oligomeric linkage is selected from the group consisting of oligomers of lactic acid, oligomers of glycolic acid, oligomers of epsilon-caproic acid, oligomers of trimethylene carbonate, and co-oligomers thereof.

10           22. The hydrogel or hydrogel precursor composition of claim 1 or 2, wherein said hydrophobic interacting groups interacts with said physical chemical protecting group through a noncovalent bond.

23. The hydrogel or hydrogel precursor composition of claim 22, wherein said hydrophobic interacting groups interacts with said physical chemical protecting group by forming an inclusion complex.

15           24. The hydrogel or hydrogel precursor composition of claim 2, wherein said molecule that disrupts an interaction between said physical chemical protecting group and said hydrophobic interacting groups is a molecule that binds to said physical chemical protecting group better than said hydrophobic interacting groups binds to said physical chemical protecting  
20   group.

25. The hydrogel or hydrogel precursor composition of claim 24, wherein said molecule that disrupts an interaction between said physical chemical protecting group and said hydrophobic interacting groups is a one-end modified polymer domain.

5           26. The hydrogel or hydrogel precursor composition of claim 25, wherein said one-end modified polymer domain comprises poly(ethylene glycol).

27. The hydrogel or hydrogel precursor composition of claim 26, wherein said polymer domain is modified on one end with a perfluorinated  
10 hydrocarbon.

28. The hydrogel or hydrogel precursor composition of claim 9, wherein said molecule that disrupts an interaction between said physical chemical protecting group and said hydrophobic interacting groups is a molecule that degrades the linkage between said physical chemical protecting  
15 group and said hydrophobic interacting groups.

29. The hydrogel or hydrogel precursor composition of claim 2, wherein said molecule that degrades the linkage between said physical chemical protecting group and said hydrophobic interacting groups is a molecule that degrades said physical chemical interacting group.

20

30. The hydrogel or hydrogel precursor composition of claim 29, wherein said molecule that degrades said physical chemical interacting group is selected from the group consisting of  $\alpha$ -amylase and amyloglucosidase.

31. A method for forming a hydrogel in contact with a tissue, said  
5 method comprising the steps of:

(a) providing a solution, said solution comprising a polymer, said polymer comprising a water soluble polymer domain having at least two hydrophobic interacting groups attached thereto, said polymer capable of assembling into a hydrogel under physiological conditions, and a physical  
10 chemical protecting group, said physical chemical protecting group preventing gelation of said polymer;

(b) providing a molecule that disrupts an interaction between said physical chemical protecting group and said hydrophobic interacting groups;

(c) combining said solution with said molecule that disrupts an  
15 interaction between said physical chemical protecting group and said hydrophobic interacting groups to form a mixture, wherein prior to, during, or after said combining, said solution and said molecule that disrupts an interaction between said physical chemical protecting group and said hydrophobic interacting groups are contacted with a tissue; and

20 (d) allowing gelation of the solution of the mixture of step (c) in contact with said tissue.

32. A method for forming a hydrogel in contact with a tissue, said method comprising the steps of:

(a) providing a solution, said solution comprising a polymer, said polymer comprising a water soluble polymer domain having at least two  
5 hydrophobic interacting groups attached thereto, said polymer capable of assembling into a hydrogel under physiological conditions, and a water soluble organic solvent, said organic solvent preventing gelation of said polymer;

(b) removing all or part of said organic solvent from said solution, wherein prior to, during, or after said removal, said solution and said organic  
10 solvent are contacted with a tissue; and

(c) allowing gelation of the solution of step (b) in contact with said tissue.

33. The method of claim 32, wherein said removing is done by evaporating all or part of said organic solvent.

15 34. The method of claim 32, wherein said removing is done by diffusion of all or part of said organic solvent.



35. A method for forming a hydrogel in contact with a tissue, said method comprising the steps of:

- (a) providing a solution, said solution comprising a polymer, said polymer comprising a water soluble polymer domain having at least two  
5 hydrophobic interacting groups attached thereto, said polymer capable of assembling into a hydrogel under physiological conditions, and a water soluble organic solvent, said organic solvent preventing gelation of said polymer;
- (b) contacting said solution with a tissue; and
- (c) allowing gelation of said solution in contact with said tissue.

36. A method for incorporating a sensitive biological material into a hydrogel composition, said method comprising the steps of:

- 5 (a) providing a solution, said solution comprising a polymer, said polymer comprising a water soluble polymer domain having at least two hydrophobic interacting groups attached thereto, said polymer capable of assembling into a hydrogel under physiological conditions, and a physical chemical protecting group, said physical chemical protecting group preventing gelation of said polymer;
- 10 (b) providing a molecule that disrupts an interaction between said physical chemical protecting group and said hydrophobic interacting groups;
- (c) providing a sensitive biological material, wherein said sensitive biological material is combined with either said solution of step (a) or said molecule that disrupts an interaction between said physical chemical protecting group and said hydrophobic interacting groups of step (b);
- 15 (d) combining said solution with said molecule that disrupts an interaction between said physical chemical protecting group and said hydrophobic interacting groups and said sensitive biological material to form a mixture; and
- (e) allowing gelation of the mixture of step (d).

37. A method for incorporating a sensitive biological material into a hydrogel composition, said method comprising the steps of:

- (a) providing a solution, said solution comprising a polymer, said polymer comprising a water soluble polymer domain having at least two  
5 hydrophobic interacting groups attached thereto, said polymer capable of assembling into a hydrogel under physiological conditions, and a water soluble organic solvent, said organic solvent preventing gelation of said polymer;
- (b) providing a sensitive biological material;
- (c) combining said sensitive biological material with said solution to  
10 form a mixture, wherein prior to, during, or after, said combining, all or part of said organic solvent is removed from said solution; and
- (d) allowing gelation of the mixture of step (c).

38. The method of claim 37, wherein said removing is done by evaporating all or part of said organic solvent.

- 15 39. The method of claim 37, wherein said removing is done by diffusion of all or part of said organic solvent.

40. A method for incorporating a sensitive biological material into a hydrogel composition, said method comprising the steps of:

- (a) providing a solution, said solution comprising a polymer, said polymer comprising a water soluble polymer domain having at least two  
5 hydrophobic interacting groups attached thereto, said polymer capable of assembling into a hydrogel under physiological conditions, and a water soluble organic solvent, said organic solvent preventing gelation of said polymer;
- (b) providing a sensitive biological material;
- (c) combining said sensitive biological material with said solution to  
10 form a mixture, wherein prior to during, or after said combining, said solution and/or said sensitive biological material is contacted with a tissue; and
- (d) allowing gelation of the mixture of step (c).

41. The method of claim 36 or 37, wherein prior to said gelation, said mixture is contacted with a tissue.

- 15 42. The method of claim 41, wherein prior to, during, or after formation of said mixture, one or more components of said mixture is contacted with a tissue.

43. The method of any of claims 31-42, wherein said polymer domain comprises poly(ethylene glycol), poly(vinyl alcohol), poly(vinyl pyrrolidone), poly(ethyl oxazoline), poly(acrylic acid), poly(acrylamide),  
20 poly(styrene sulfonate), poly(amino acids), polysaccharides, or copolymers thereof.

44. The method of claim 43, wherein said polymer domain is poly(ethylene glycol).

45. The method of any of claims 31-42, wherein said hydrophobic interacting groups are hydrocarbons.

46. The method of claim 45, wherein said hydrocarbons are perfluorinated hydrocarbons.

5 47. The method of claim 31 or 36, wherein said physical chemical protecting group is a cyclodextrin.

48. The method of claim 47, wherein said cyclodextrin is  $\beta$ -cyclodextrin.

10 49. The method of claim 31 or 36, wherein said physical chemical protecting group is a molecule that covalently binds to said hydrophobic interacting groups.

50. The method of claim 49, wherein said molecule that covalently binds to said hydrophobic interacting groups is hydrophilic.

15 51. The method of any of claims 30-41, wherein said polymer domain is poly(ethylene glycol) and said hydrophobic interacting groups are perfluorinated hydrocarbons.

52. The method of claim 31 or 36, wherein said polymer domain is poly(ethylene glycol), said hydrophobic interacting groups are perfluorinated hydrocarbons, and said chemical protecting group is  $\beta$ -cyclodextrin.

53. The method of any of claims 31-42, wherein said polymer is linear.

54. The method of any of claims 31-42, wherein said polymer is branched.

5 55. The method of claim 54, wherein said polymer comprises multi-arm poly(ethylene glycol).

56. The method of any of claims 31-42, wherein said hydrophobic interacting groups are positioned at the termini of said polymer domain.

57. The method of any of claims 31-42, wherein said hydrophobic  
10 interacting groups are positioned within the domain of said polymer domain.

58. The method of any of claims 31-42, wherein the linkage between said polymer domain and said hydrophobic interacting groups is stable.

59. The method of any of claims 31-42, wherein the linkage between said polymer domain and said hydrophobic interacting groups is degradable.

15 60. The method of claim 59, wherein said degradable linkage is selected from the group consisting of an anhydride linkage, an ester linkage, a carbonate linkage, an amide linkage, and an oligomeric linkage.

61. The method of claim 60, wherein said oligomeric linkage is selected from the group consisting of oligomers of lactic acid, oligomers of glycolic acid, oligomers of epsilon-caproic acid, and oligomers of trimethylene carbonate.

5           62. The method of claim 31 or 36, wherein said hydrophobic interacting groups interacts with said physical chemical protecting group through a noncovalent bond.

63. The method of claim 31 or 36, wherein said hydrophobic interacting groups interacts with said physical chemical protecting group by  
10           forming an inclusion complex.

64. The method of claim 31 or 36, wherein said molecule that disrupts an interaction between said physical chemical protecting group and said hydrophobic interacting groups is a molecule that binds to said physical chemical protecting group better than said hydrophobic interacting groups bind  
15           to said physical chemical protecting group.

65. The method of claim 64, wherein said molecule that disrupts an interaction between said physical chemical protecting group and said hydrophobic interacting groups is a one-end modified polymer domain.

66. The method of claim 65, wherein said one-end modified  
20           polymer domain comprises poly(ethylene glycol).

67. The hydrogel or hydrogel precursor composition of claim 66, wherein said polymer domain is modified on one end with a perfluorinated hydrocarbon.

68. The method of claim 31 or 36, wherein said molecule that  
5 disrupts an interaction between said physical chemical protecting group and said hydrophobic interacting groups is a molecule that degrades the linkage between said physical chemical protecting group and said hydrophobic interacting groups.

69. The method of claim 31 or 36, wherein said molecule that  
10 degrades the linkage between said physical chemical protecting group and said hydrophobic interacting groups is a molecule that degrades said physical chemical protecting group.

70. The method of claim 69, wherein said molecule that degrades said physical chemical protecting group is selected from the group consisting of  
15  $\alpha$ -amylase and amyloglucosidase.

71. The method of claim 32, 33, 34, 35, 36, 37, 39, 40, 41, or 42, wherein said organic solvent is N-methylpyrrolidone.



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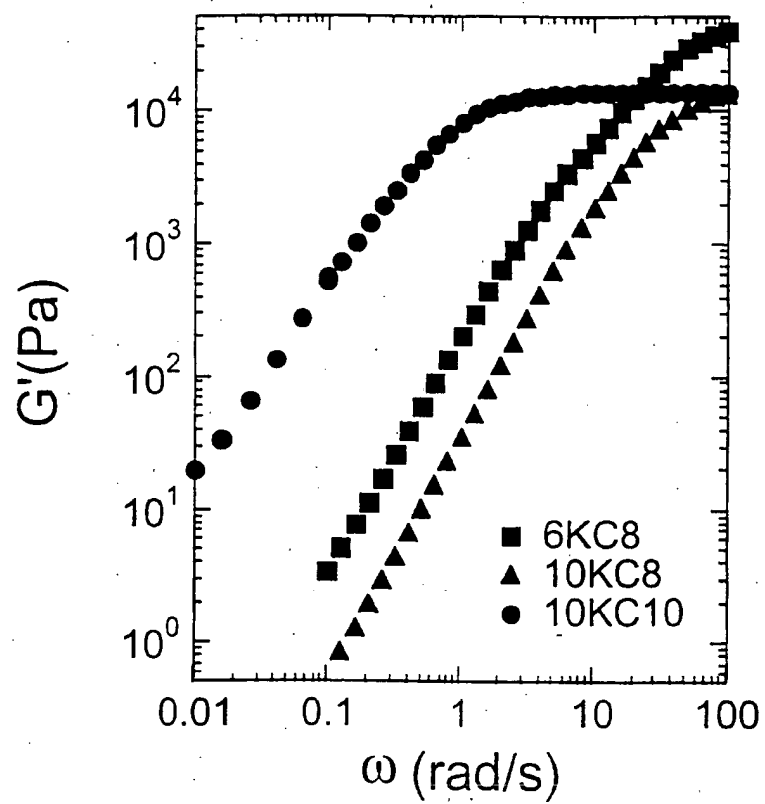


FIG. 1

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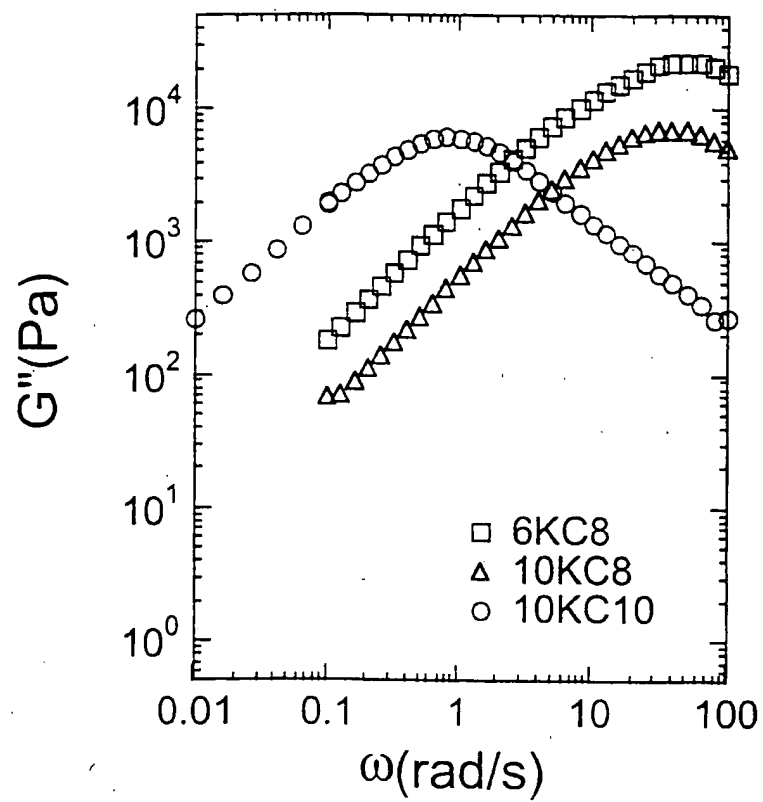
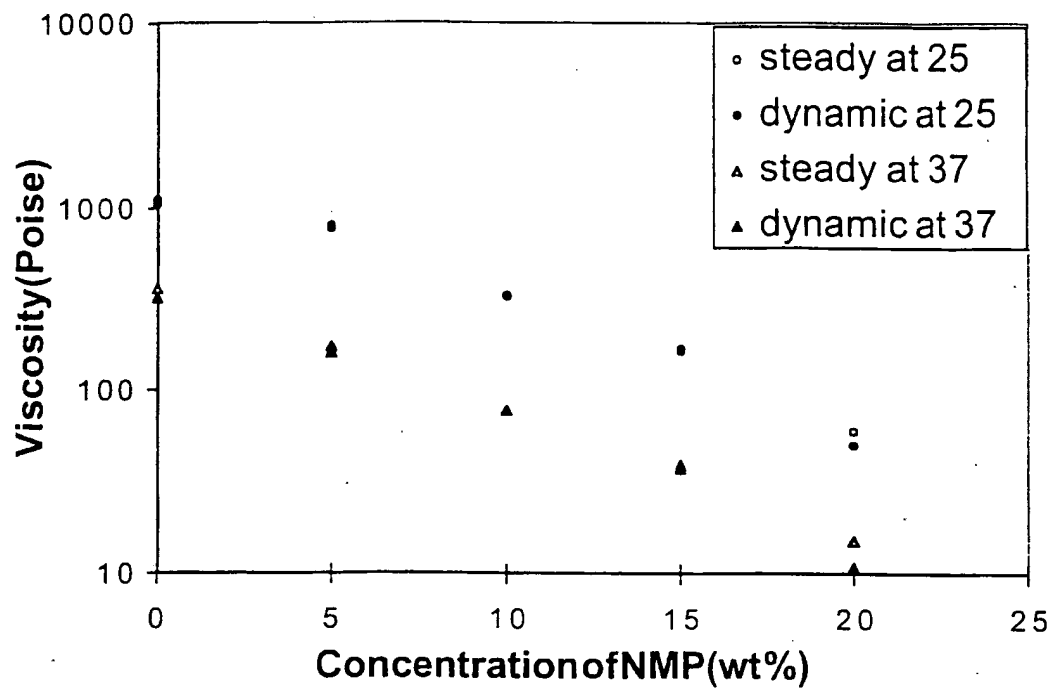
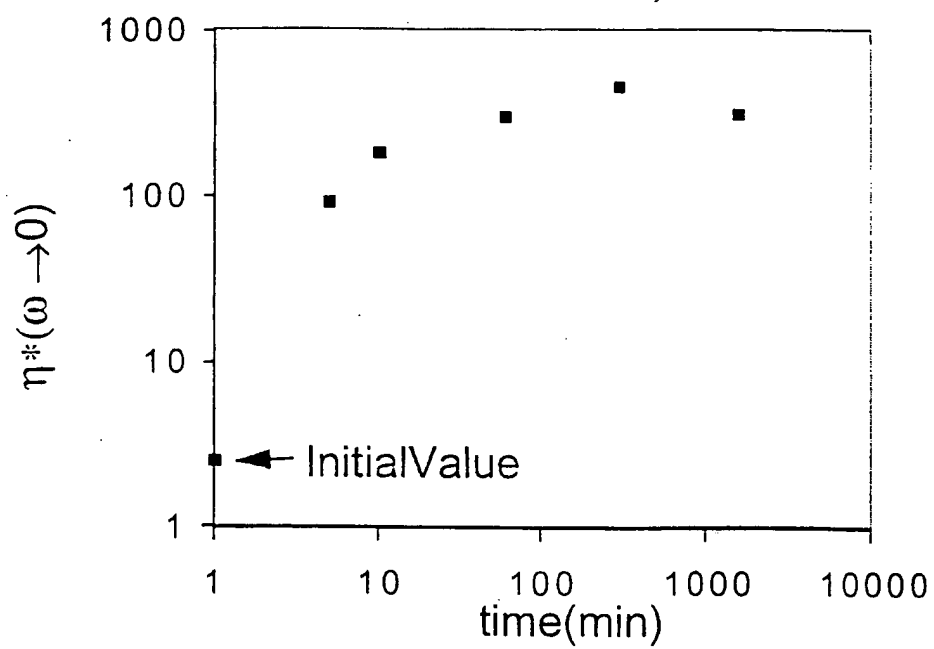


FIG. 2

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**FIG. 3**

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**FIG. 4**

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/11691

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(7) : C08L 71/02, 05/16; C08G 65/08, 65/323; A61K 31/77

US CL : 523/105, 113; 524/48, 612, 916; 424/426, 486; 514/12, 21

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 523/105, 113; 524/48, 612, 916; 424/426, 486; 514/12, 21

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,560,929 A (HEDSTRAND et al.) 01 October 1996, abstract, column 3, lines 24-68, column 4, lines 1-16, column 5, lines 29-35,	1-3, 5, 13, 17-20, 24
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Y	column 6, line 64 to column 7, line 55 and example 2.	----- 1-3, 5, 13, 17-20, 24
Y, P	US 5,976,648 A (LI et al.) 02 November 1999, abstract, column 1, lines 14-23, column 2, line 52 to column 3, line 13 and column 5, lines 5-15.	1-71
A	US 5,278,201 A (DUNN et al.) 11 January 1994, abstract, column 2, line 52 to column 3, line 26, column 4, lines 47-69, and example 1, column 13, lines 1-43.	1-71

☐ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

13 JULY 2000

Date of mailing of the international search report

31 JUL 2000

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# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/11691

## B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

EAST

search terms: hydrogel, cyclodextrin, gel preventing, gel prevention, (hydro)gel precursor, hydrocarbon, fluorocarbon, hydrophob(ic) association